Time Management
in the High Level Architecture

Integrated Training Program

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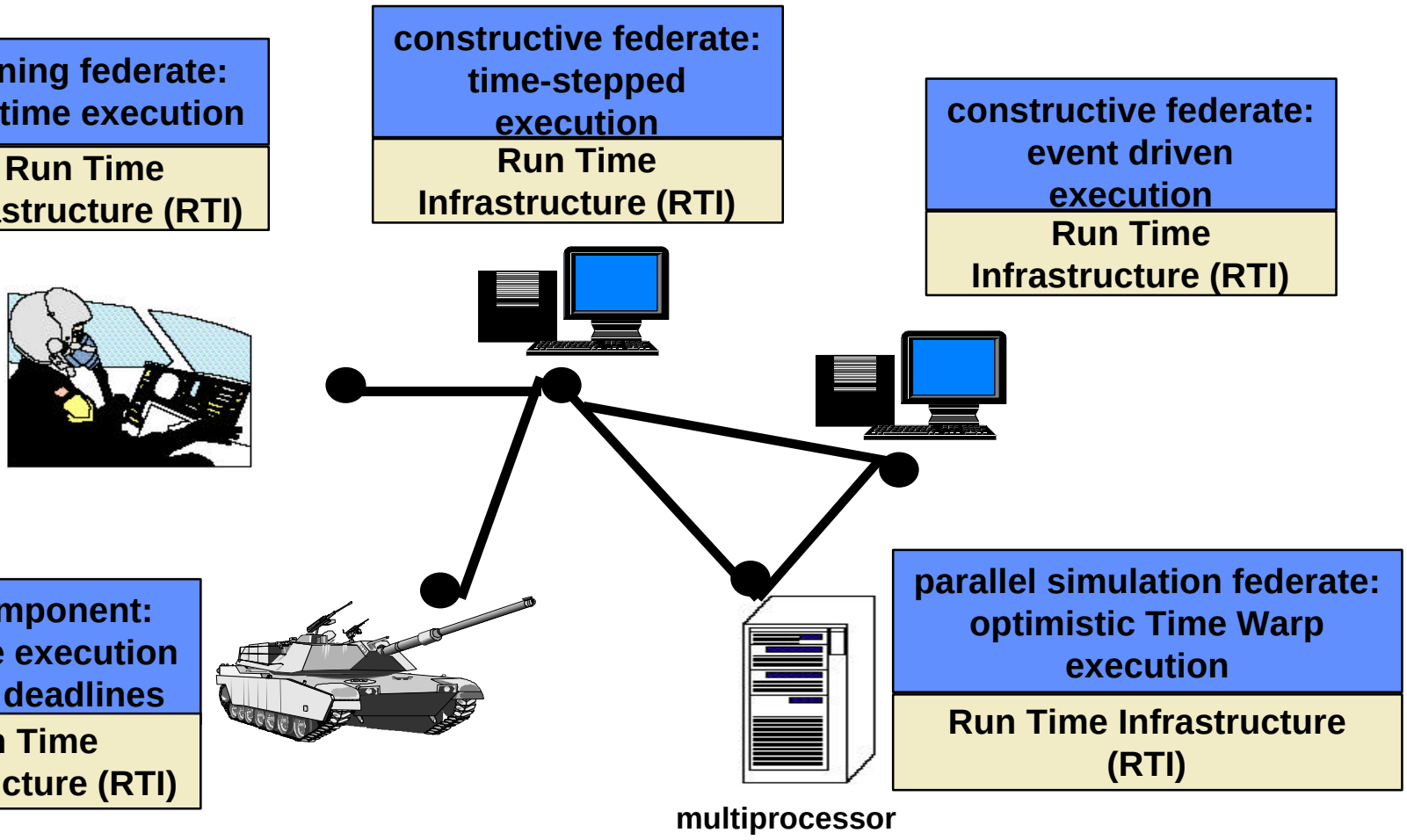
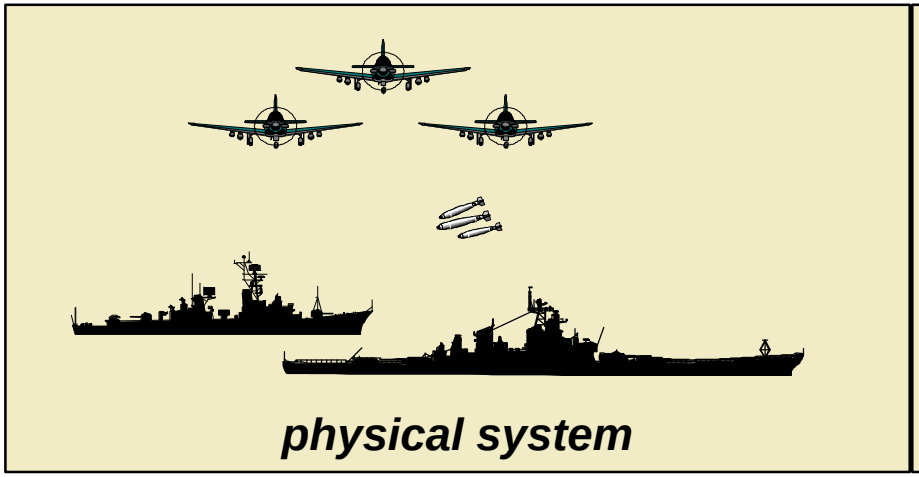
Challenge: Time Management Interoperability



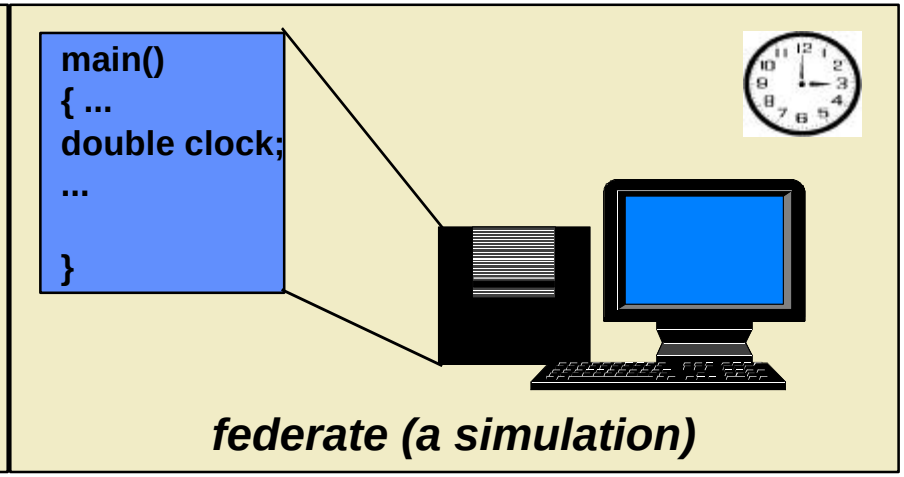
Goal: provide services to support interoperability among federates with different local time management schemes in a single federation execution.
Observation: RTI by itself cannot guarantee interoperability.

Time

- Physical system: the actual or imagined system being modeled
- Simulation: a system that emulates the behavior of a physical system



physical system



federate (a simulation)

- Physical time: time in the physical system (e.g., 0000 to 1700 hours, December 7, 1941)
- Simulation time: representation of physical time within the simulation
  - Federation time axis (FTA): a totally ordered sequence of values representing physical time (floating point values in interval [0.0, 17.0])
  - Federate time: a specific federate's current point on FTA (e.g., 4.0)
- Wallclock time: time during the execution of the simulation, usually output from a hardware clock (e.g., 1330 to 1700 hours on February 24, 1997)

Time Management

Time management is concerned with the mechanisms used by federates to advance along the federation time axis

- **Paced vs. Unpaced Execution**
  - **(Scaled) Real-time Execution: Each federate is paced so federate time advances at a rate S times faster or slower than wallclock time**
  - **As-Fast-as-Possible Execution: No fixed relationship exists between advances in federate and wallclock time**
- **Independent vs. Coordinated Time Advances**
  - **Independent (e.g., training): Each federate advances its federate time independently of other federates**

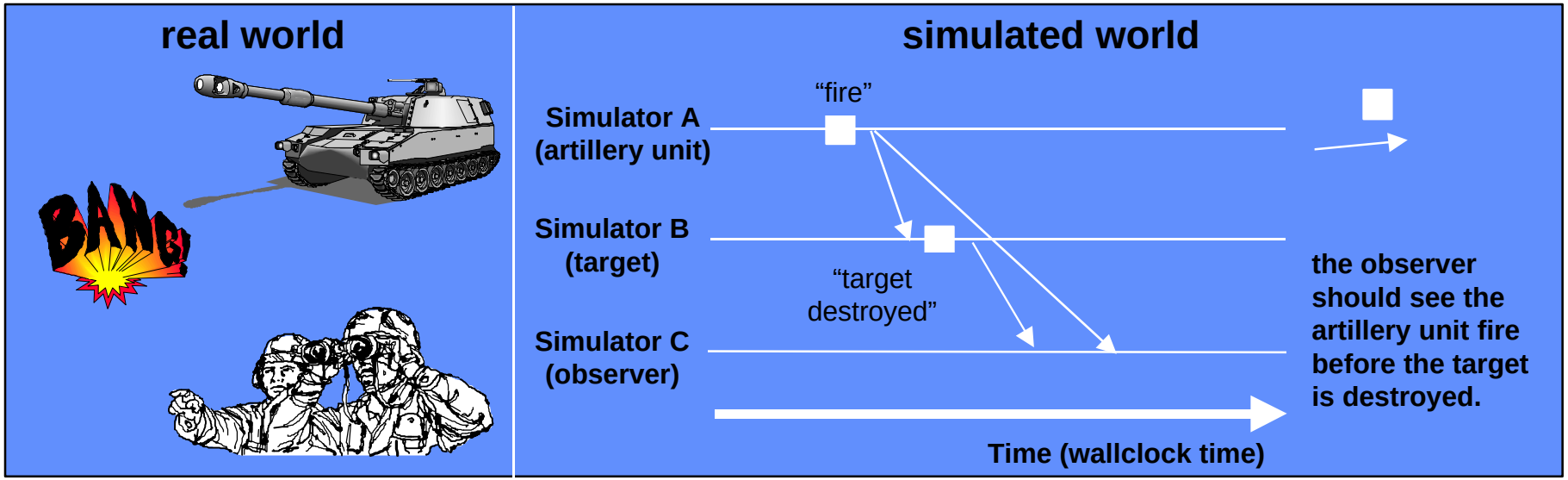
    Federate time same as wallclock time (scaled, plus an offset)
  - **Coordinated (e.g., analysis): Time advances are coordinated to ensure the federation preserves before/after relationships in the physical system**

    Federate time same as logical time

example	paced?	time advance
DIS training exercise	*yes*	*independent*
ALSP (human-in-the-loop)	*yes*	*coordinated*
ALSP (as-fast-as-possible)	*no*	*coordinated*

Causality

- "Things" happen in the real world in a certain order (e.g., cause & effect)
- It should appear that events in the simulated world happen in the same order as the real world actions that they represent



Causality: If event A *"happens before"* event B, the message for A should be delivered before the message for B

- If the message for the "fire" event is delayed in the network, the observer will "see" the target is destroyed before the artillery unit fired upon it!
- Temporal anomalies such as this may or may not be acceptable, depending on the federation's goals

Message Ordering Services

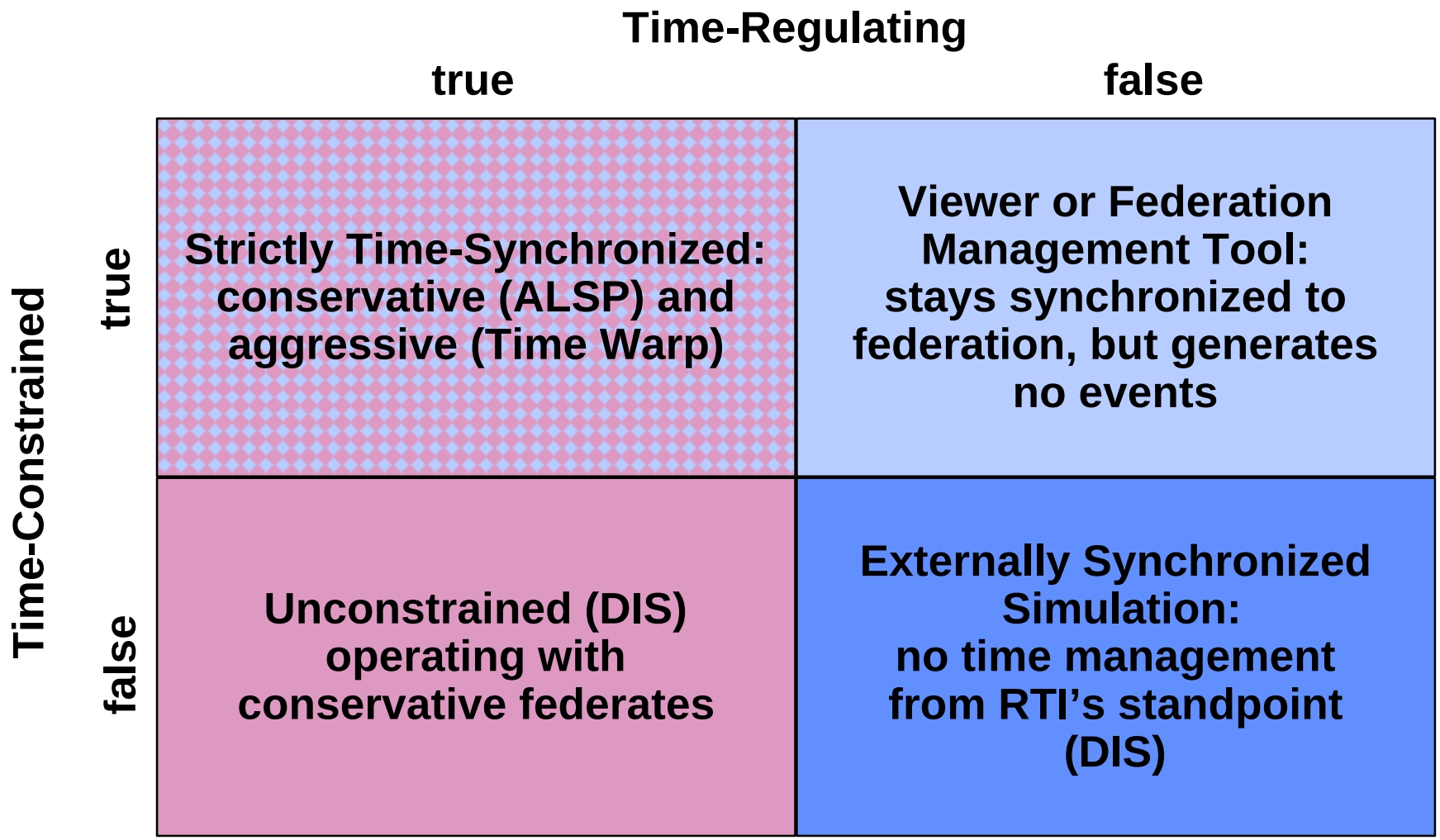
The baseline HLA provides two types of message ordering:

- **Receive Order: messages passed to federate in order of reception**
- **Time Stamp Order (TSO): successive messages passed to federate have non-decreasing time stamps**

Property	Receive Order	Time Stamp Order (TSO)
Latency	*low*	*higher*
Reproduce before and after relationships?	*no*	*yes*
All federates see same ordering of events?	*no*	*yes*
Execution repeatable?	*no*	*yes*
Typical applications	*training, T&E*	*analysis*

- **Receive order minimizes latency, does not prevent temporal anomalies**
- **TSO prevents temporal anomalies, but has somewhat higher latency**

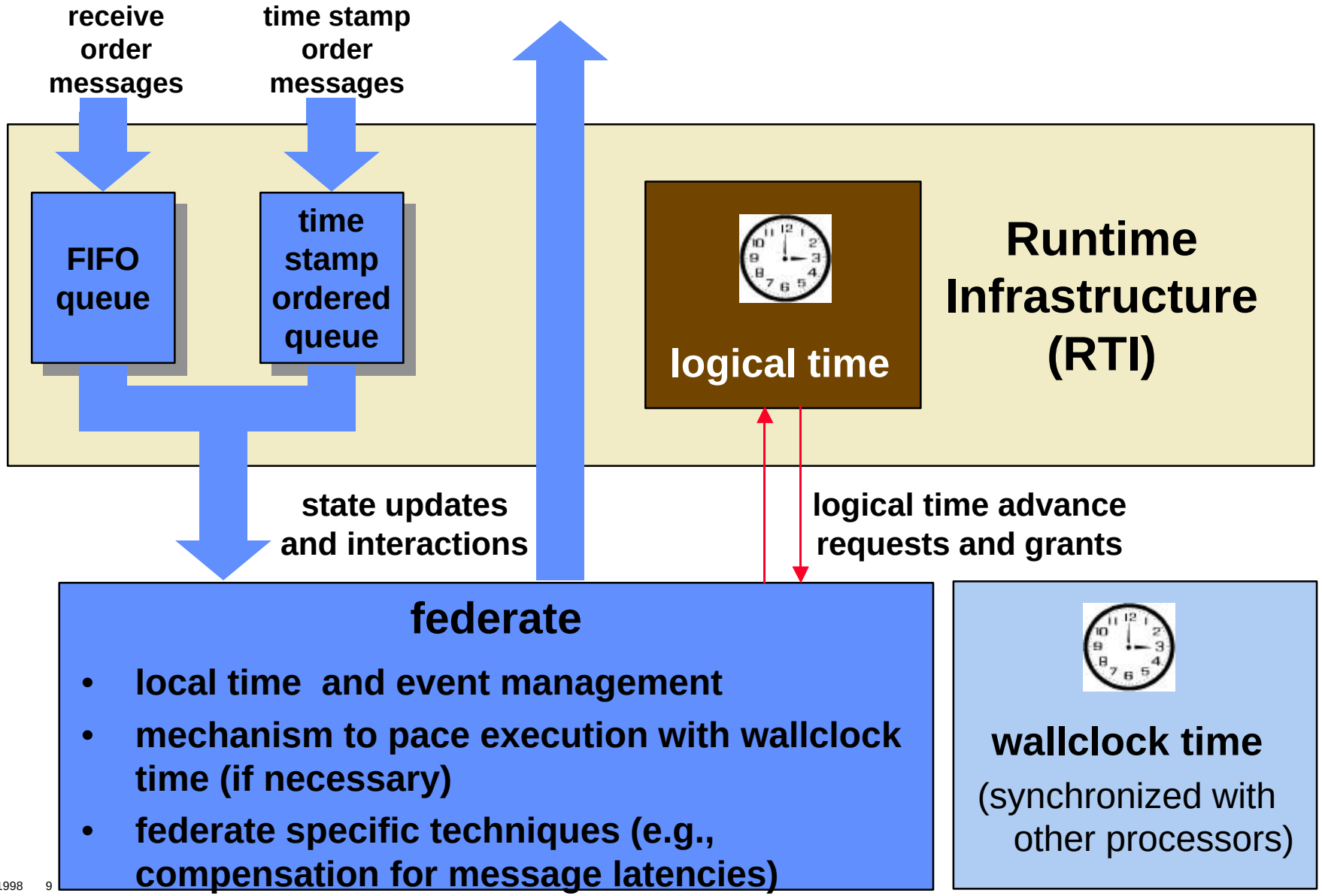
Time Management Seeks to Accommodate a Variety of Schemes in a Single Federation



Logical Time

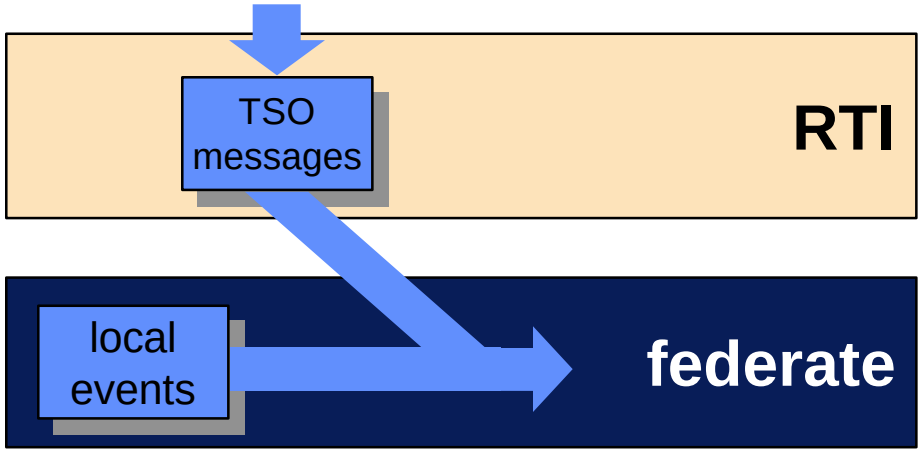
- **Classical discrete event simulation programs process all events in time stamp order**
- **A mechanism is required to enable federates to interleave processing of local events with those received from other federates**
- **Logical time (applicable to coordinated time advance federates):**
  - **If the logical time of a federate is T, the RTI guarantees no more TSO messages will be passed to the federate with time stamp < T**
  - **Local events with time stamp < T can be "safely" processed**
  - **Logical time in a federate only advances when that federate explicitly requests an advance:**
    - **Time Advance Request (T): requests advance to time T**
    - **Next Event Request (T): requests advance to time stamp of next TSO message, or T, which ever is smaller**
    - **RTI issues Time Advance Grant (T') when logical time advanced to T'**
  - **Federates responsible for pacing logical time advances with wallclock time in (scaled) real-time executions**

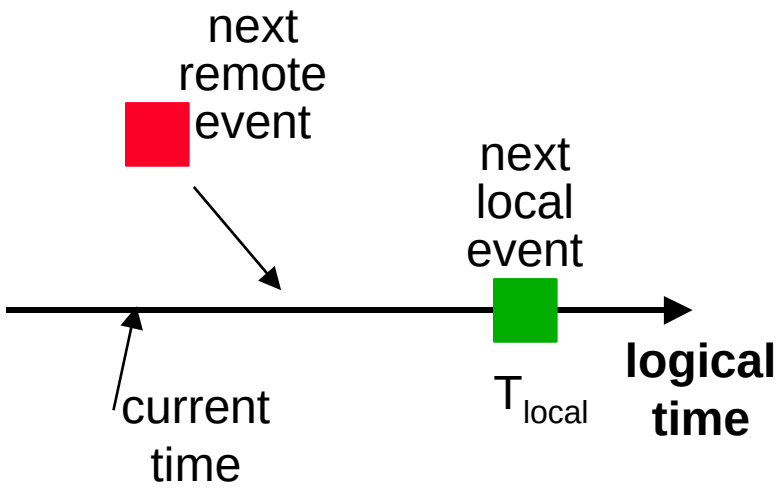
Time Management Services



Example:
Event Driven Federate

Goal: merge TSO messages (events from other federates) with local events so all events are processed in time stamp order





while (simulation still in progress)

invoke Next Event Request (T_{local} = time stamp of next local event)

RTI delivers next TSO event w/ time stamp Š T_{local} if any exist (+ others w/ same time stamp)

RTI advances federate's logical time, invokes Time Advance Grant

if (TSO message(s) delivered in above Next Event Request service call)

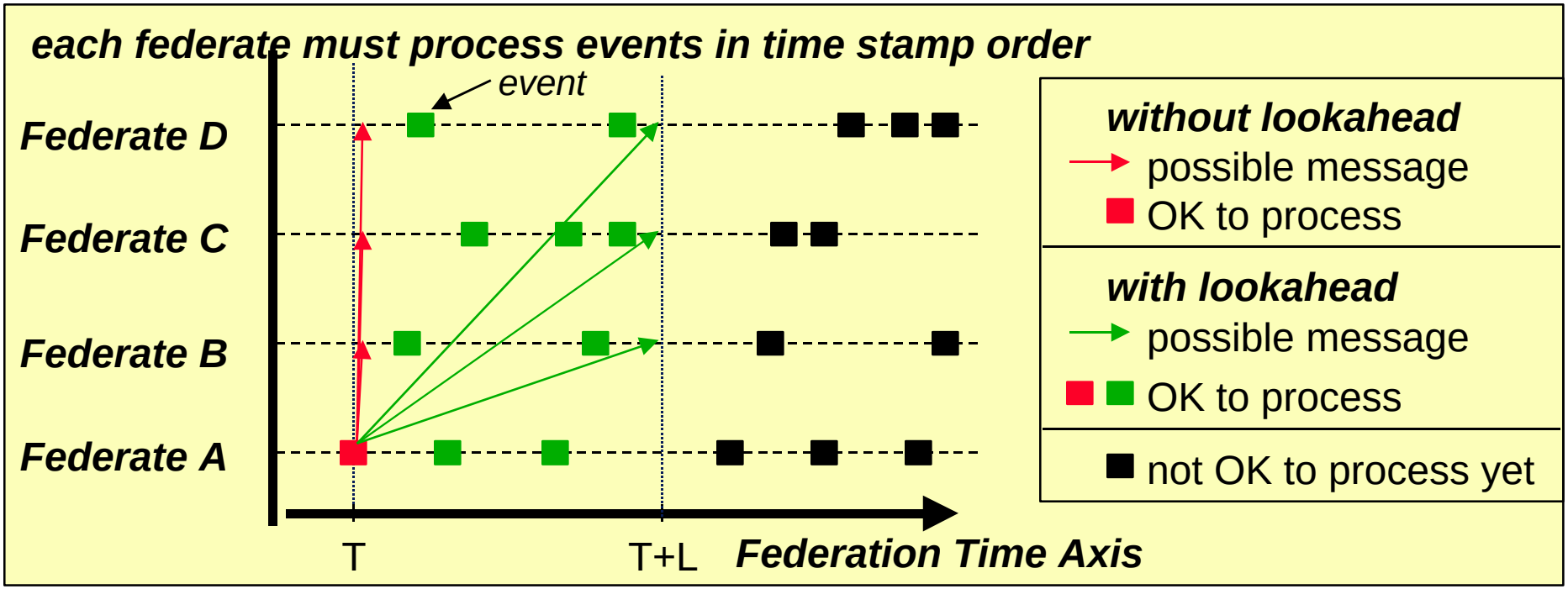
process the remote event(s) delivered to the federate

else

process next local event

Lookahead

- **Each federate using logical time declares a lookahead value L; the time stamp of any TSO event generated by the federate must be at least the federate's current time + L**
- **Applies only to federates using logical time and TSO events**
  - **Lookahead may change during the execution, but can't decrease instantly**



Lookahead is necessary to allow concurrent processing of events with different time stamps (unless optimistic event processing is used)

Optimistic Time Management Services

- **Mechanisms to ensure events are processed in time stamp order:**
  - **Conservative: protocols to *avoid* out of order event processing (e.g., CMB)**
  - **Optimistic: *detect* out-of-order event processing, *recover* (e.g., Time Warp)**
- **Requirements**
  - **Support federations including conservative and/or optimistic federates**
  - **Federates not aware of local time management mechanism of other federates (optimistic or conservative)**
  - **Optimistic events (events that may be later canceled) cannot be delivered to conservative federates that cannot roll back**
  - **Optimistic events should be delivered to other optimistic federates**
  - **Individual federates may be sequential or parallel simulations**
- **HLA time management services for optimistic federates:**
  - **Early release of messages to optimistic federates (Flush Queue Request and Grant)**
  - **Cancellation of previously sent messages: anti-messages (Retract)**
  - **Provide sufficient information to optimistic federate to compute *Global Virtual Time* locally (LBTS)**

Summary: HLA Time Management

- **Functionality:**
  - Allows a variety of styles of federation executions
    - Real-time vs. scaled real-time vs. as-fast-as-possible executions
    - No causal guarantees vs. repeatable, causal executions
  - Allows federates with different time management requirements (and local TM mechanisms) to be combined within a single federation execution
  - DIS-style training simulations
    - Simulations with hard real-time constraints
    - Event-driven simulations
    - Time-stepped simulations
    - Optimistic simulations
- **HLA Time Management Services:**
  - Receive order and time stamp order message delivery
  - Logical time
    - Time advance mechanisms
    - No TSO messages in a federate's "past"